An application of the Multi-Level DG-FDTD to the analysis of the transmission between a dipole in free space and an implanted antenna in a simplified body model with various positions

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An Application of the Multi-Level DG-FDTD to the Analysis of the Transmission Between a Dipole in Free-Space and an Implanted Antenna in a Simplified Body Model with Various Positions

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***Abstract*— We propose to use the advantages of the multi-level dual-grid finite-difference time-domain (DG-FDTD) method to determine, in a short computation time, the transmission between an antenna implanted in a simplified homogeneous body model and a half-wavelength dipole (at 402 MHz) located in free space. The transmission coefficient is determined for four different positions of the body.**

I. Introduction

Medical implant communications systems (MICS) are a growing application field in the Body Area Network (BAN) context [1]. The determination of power transmission between an implanted antenna and an external antenna is a major issue that requires time consuming simulations [2].

Among the classical numerical methods, the FDTD has become very popular for the study of electromagnetic problems involving the human body as propagation channel [3]. Nevertheless, its uniform cubical mesh often leads to oversampled areas, especially in the case of the study of transmission between medical implant in human body and external antenna in free space. Indeed, due to their small size, implanted antennas usually require a much more precise description than the human body, which can still demand a finer description than the antenna in free space.

In order to deal with this oversampling problem, some subgridding FDTD schemes have been used or investigated for the BAN context [4], [5]. However, the resultant interpolation process of this approach might generate instabilities when computing the field components at the interface between two different areas of the FDTD volume.

A way to overcome this issue, is to use an extension of the DG-FDTD method, whose original principle is detailed and illustrated in [6] and [7]. The new multi-level DG-FDTD consists in splitting the overall simulation into several classical FDTD simulations sequentially executed with an appropriate mesh in order to respect the constraints of each element.

First we present the configuration of a typical problem involving the human body as the propagation channel. Then the multi-level DG-FDTD decomposition of the problem is described. Finally, the advantages of the method are highlighted by analyzing the transmission coefficient between a half wavelength dipole in free space and an implanted antenna in a homogeneous body model with different positions.

II. Description of the Problem

The problem configuration is illustrated in figure 1.

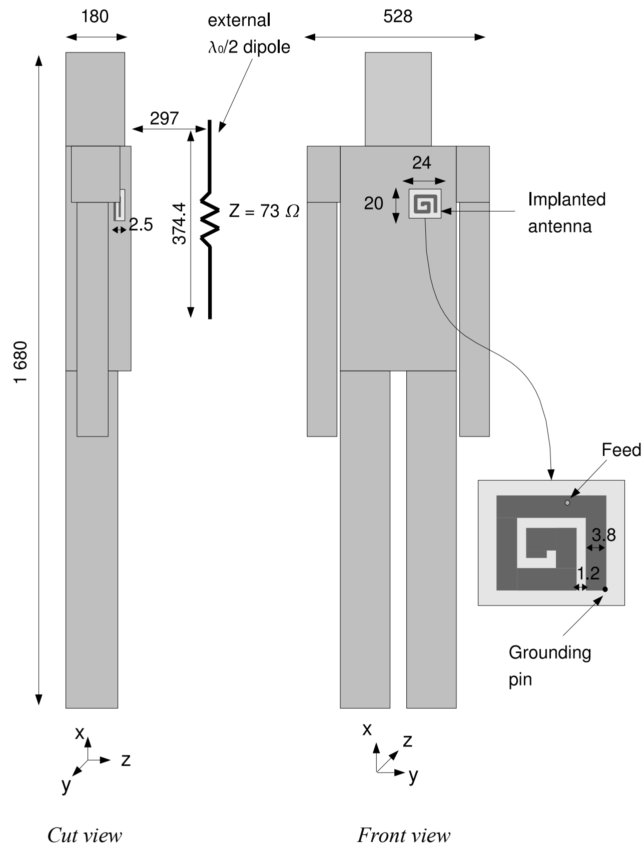

Fig. 1 *Implanted antenna in a simplified homogeneous body model placed in front of a $\lambda_0/2$ dipole at f_0 = 402 MHz (Unit mm)*

A medical implanted antenna, whose original description can be found in [8], is placed in a homogeneous simple block model, inspired from [9]. The dimensions of the body model are described in table I. We are interested in the transmission between the implanted antenna placed in the left upper chest part of the human body model and a half wavelength dipole located in front of the body model.

TABLE I

DIMENSIONS OF THE CUBIC BODY MODEL

	Lx (mm)	Ly (mm)	Lz (mm)
Head	240	192	165
Chest	576	336	180
Shoulder	144	96	135
Arm	600	86.4	90
Leg	864	144	150

The three main elements of this problem (implanted antenna, human body and external antenna) all require a different level of mesh accuracy. Thus, the multi-level DG-FDTD technique is applied here using three steps described in the next section and illustrated in figure 2. We consider here a simplified example, but the proposed method could also be applied to a more realistic problem.

III. MULTI-LEVEL DG-FDTD DECOMPOSITION OF THE PROBLEM

A. First step

The first step corresponds to a very fine description of the implanted antenna contained in a homogeneous medium with muscle tissue characteristics at 402 MHz (ε_r = 58.8 and σ = 0.84 S/m). The volume is limited by perfectly matched layers (PMLs) so that an infinite open problem is considered. A near field surface is placed around the antenna in order to store the accurate primary radiation of the isolated antenna. At the end of this step, we can determine the isolated antenna characteristics.

B. Second step

The primary radiation is then used as the excitation of an intermediate FDTD volume with the left upper chest part of the body model containing the implant. Only the part of the body model which interacts the most with the implanted antenna is described. The accurate primary radiation is injected through an excitation surface, using the total-field / scattered-field decomposition principle [10]. Unlike subgridding schemes, only one interpolation is performed between each step. Thus, the field components are interpolated once, from a fine mesh to a less fine mesh.

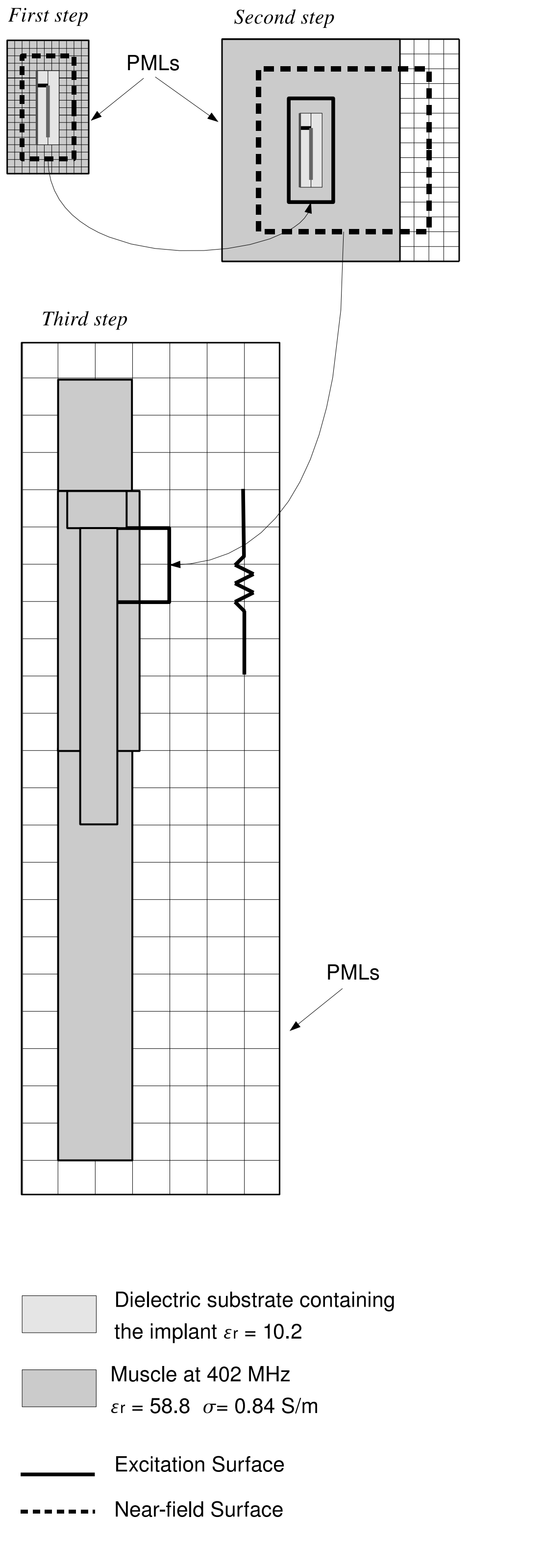

Fig. 2 Multi-level DG-FDTD decomposition of the problem

The implanted antenna, which is located in the scattered-field region, is also described with the intermediate mesh, in order to take into account the effects of the backscattered field on its input impedance. So at the end of this step we can determine the surrounded antenna characteristics. The whole intermediate volume is surrounded by PMLs in order to simulate an infinite open problem. A new near-field surface stores the radiation of the implanted antenna contained in the left upper-chest part of the body. We name it the secondary radiation.

C. Third step

The secondary radiation is used as the excitation of a coarse volume containing the whole body and the receiving dipole. Once again, the excitation is carried out by an excitation surface, using the total-field / scattered-field decomposition principle. This time it is not necessary to describe the implanted antenna as the main effects of the backscattered field have already been taken into account during the previous step.

Note that near-field data stored at the end of each step can be re-used in different configurations of environment without having to simulate again the previous steps.

IV. Evolution of the Transmission Coefficient Considering Different Body Positions

We propose to determine the transmission between the implanted antenna and the external dipole for four different positions of the body model left arm. The four different positions of the arm are described in figure 3.

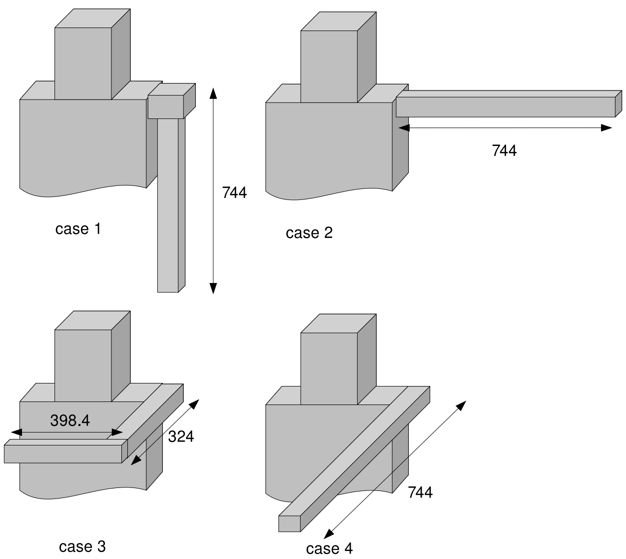

Fig. 3 Partial views of the different body positions

For each new position studied, only the last coarse step needs to be simulated again. Indeed, one of the main advantages of this method is the possibility of reusing near-field data, stored after each step of the simulation, in new environment configurations. This particularity is really interesting in terms of computational time as the last coarse step takes only from 1 hour and 11 minutes to 2 hours and 23 minutes, depending on the position of the left arm.

The parameters of the multi-level DG-FDTD simulation and the computation time of the different steps are summarized in table II.

TABLE II
PARAMETERS OF THE MULTI-LEVEL DG-FDTD SIMULATION

	1st step (fine mesh)	**2nd step** (intermediate mesh)	**3rd step** (coarse mesh)
Spatial steps			
dx = dy	0.4 mm	1.2 mm	4.8 mm
dz	0.5 mm	1.5 mm	3 mm
Time step	0.77958 ps	2.3387 ps	7.1181 ps
N_x x N_y x N_z (including PMLs)	101x91x45	124x124x74	390x150x199 (case 1) 390x275x199 (case 2) 390x150x199 (case 3) 390x150x298 (case 4)
Computation time	25 min	26 min	1h 11min (case 1) 2h 23min (case 2) 1h 11min (case 3) 1h 48min (case 4)

Simulations have been performed for a dipole situated at 29,7 cm from the body model chest. The magnitude of the S_{21} parameter is plotted versus the frequency in figure 4. We take into account the evolution of the S_{21} coefficient in the [350 450] MHz frequency band. Indeed, in this frequency band, the dielectric characteristics of muscle don't vary significantly : from 0.78 to 0.80 $S.m^{-1}$ for the conductivity and from 45.7 to 48 for the relative permittivity. Note that a dispersive FDTD could be used for larger bandwidth, but it would not change the principle of the proposed approach.

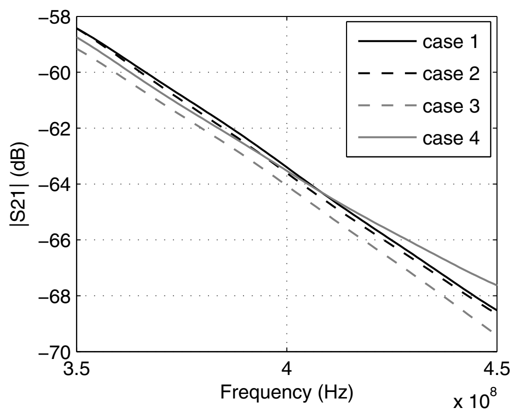

Fig. 4 *Evolution of the transmission coefficient for different body positions*

We can observe that the position of the left arm does not modify significantly the transmission between the implanted antenna and the external dipole. The transmission coefficient is not even altered when the arm is bent between the body and the dipole in the third case.

V. Conclusion

The multi-level DG-FDTD turns out to be well-suited for the study of the transmission between implant and external antennas, since such problems usually contain elements which require different levels of mesh accuracy. The possibility of reusing near-field data, stored after each step of the simulation, permits to considerably reduce computation time. This particularity has been applied here to the study of different body positions. Thus for each new positions, only the last coarse step has to be simulated again.

Acknowledgment

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